The need for country masks for future national greenhouse gas flux estimations

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Abstract

The Paris Agreement requests a substantial reduction of greenhouse gas (GHG) emissions. These emissions are currently mainly estimated from bottom-up inventories and process-based models of land and ocean fluxes. Another, complementary approach is based on measurements of the atmospheric GHG concentration in combination with atmospheric inverse modelling to provide the GHG fluxes. For the latter approach the GIScience community should contribute with providing an appropriate country mask to enable estimations of national budgets. This paper aims at describing the requirement of such a country mask as well as report on technical solutions for preliminary tests we made on national GHG flux estimations.

Keywords: greenhouse gas estimation, inverse modelling, geodata, spatial interpolation, country mask

1 Introduction

The Paris Agreement aims to maintain the increase in the global average temperature to well below 2 °C above pre-industrial levels and hence requests a substantial reduction of greenhouse gas (GHG) emissions. These emissions are currently mainly estimated from bottom-up inventories, e.g. the annual national reporting of anthropogenic GHG emissions under the UNFCCC (United Nations Framework Convention on Climate Change), and process-based models of land and ocean fluxes (Global Carbon Project, Le Quéré et al., 2017).

Another, complementary approach is based on measurements of the atmospheric GHG concentration in combination with atmospheric inverse modelling to provide a mass-balance constraint of GHG fluxes (cf. Leip et al., 2018). This so-called top-down approach is well-suited to assess and verify national bottom-up inventories of GHGs with mostly anthropogenic sources, because it is independent of the national reports. For CO_2, land and ocean fluxes are equally important and in this case the bottom-up approach constrains the location of the total surface fluxes from all sources.

The top-down approach relies on high quality long term GHG observations and a standardised methodology to quality control and distributes these observations. To meet these requirements in Europe ICOS has been established, which received the official status as a European research infrastructure, ERIC, in 2015 (https://www.icos-ri.eu/). ICOS now has 12 member countries and involves more than 120 measurement locations where GHG concentrations and fluxes are observed; the plan is to expand to many more countries and stations in the near future. All observed data is quality controlled through the ICOS thematic centers: Ecosystem, Atmospheric and Ocean Thematic Centers and a Central Analytical Laboratory. The data is then distributed through ICOS Carbon Portal which is also responsible for collecting and facilitating the creation of elaborated products based on these measurement data, like inversion-based GHG budget estimates (https://www.icos-cp.eu/).

The GIScience community should contribute to the top-down approach for estimating national GHG fluxes with providing an appropriate country mask based on a standardised grid system (e.g. following the recommendations from the Open Geospatial Consortium, OGC, working group Discrete Global Grid Systems SWG). This paper aims at describing the requirement of such a country mask as well as report on technical solutions for preliminary tests we made on national GHG flux estimations.

2 Methodology

2.1 Inverse modelling

In recent years, regional atmospheric inversions systems with increased spatial resolution have been developed to better exploit the growing atmospheric measurement network (e.g. in Europe) and thus to provide improved estimates of the GHG fluxes at the continental and sub-continental scale with the ultimate goal of determining national GHG budgets.

The general set-up of an atmospheric inversion system consists of an atmospheric transport model to relate land and ocean fluxes to changes in atmospheric concentrations, together with an optimization scheme to find those fluxes that best match the atmospheric measurements. Figure 1 shows a schematic set-up of an inversion system and its components.

The first step of an inversion is to compute the concentrations corresponding to a set of a-priori surface fluxes (available from process-based models) and to compare these concentrations to the observed ones. The resulting model-data mismatches are then used to compute a correction to the a-priori fluxes. This correction represents the best statistical compromise between fitting the observations and not deviating too much from the a-priori fluxes. Due to computational constraints the optimal solution has to be approximated iteratively.

The three-dimensional atmospheric transport models used to compute the transport and dispersion of emitted trace gases according winds and turbulence are based on meteorological models and/or operational reanalysis of meteorological observations and hence use the same grid definitions and land/sea distributions as these driving models. The final results of an inversion are optimized GHG fluxes on the transport model grid together with estimates of their uncertainty.

In the ongoing EUROCOM project optimized CO_2 flux estimates from a number of inverse modelling systems are compared on European level. These inversion systems differ in several aspects, e.g. regarding the transport model and the optimisation scheme. The aim of the comparison is to better characterize the robustness of the flux estimates and to access uncertainties of the optimized fluxes related to the structural differences in the systems. Model results in the project are provided on transport model-specific grids and hence differ in spatial resolution (ranging from 0.25° to 1°).

From a GIScience perspective it is interesting to note that the transport models in these inversion systems, in most, if not all cases, utilize a spherical earth model. The question is then how the location of the input geographic data (such as land/sea masks, topography, vegetation data, etc.) to the inverse model is treated. If the coordinates based on an ellipsoid (most commonly GRS80) are simply mapped to a sphere, there will be a shift along the meridian. In geodetic terms this is almost the same as using geodetic latitude (which is the common latitude on an ellipsoid) value for the geocentric latitude (see Snyder, 1987, p. 13 for definition). By using the relationships between the geocentric and geodetic latitudes it is found that the shift along the meridian is at most around 20 km (in mid latitudes); the exact value depends on the size of the spherical earth model. How this shift will affect the inverse models are, to our knowledge, not investigated. But there have been studies on the effect of using a spherical approximation (without considering the latitude shift) in weather prediction modelling. Cao (2017, p. 3426) concludes that there are differences in predictions using spherical or ellipsoidal earth models and that they are caused by “(1) topography shift, including elevation, land use, albedo, and LAI differences, and (2) latitude-dependent physics, such as the Coriolis force and the incoming solar radiation”. It is reasonable to assume that these circumstances will also affect the inverse modelling, but if the effect is significant remains to be studied. We should also point out that it might as well be so that several research groups take this horizontal shift into account in their studies.

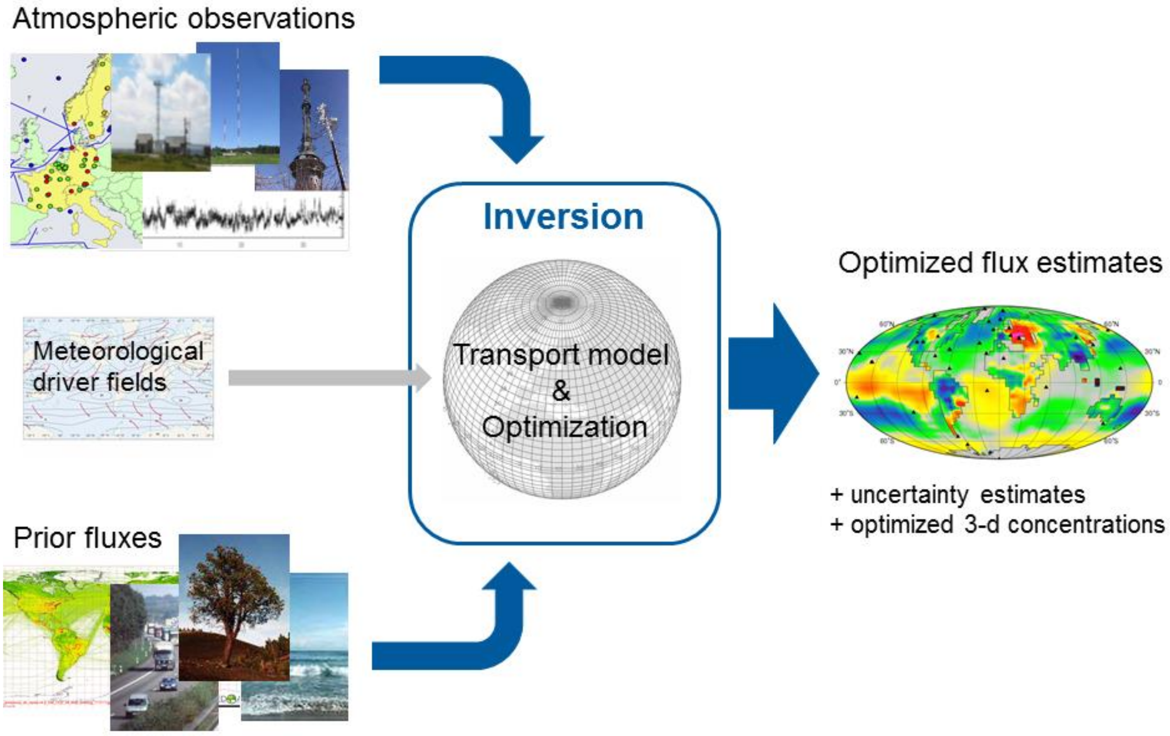

Figure 1. Schematic set-up of an inversion system.

2.2 Estimating carbon flux on national level

The outcome of the inverse models is carbon fluxes estimated on a grid. Depending on the model used, the fluxes could be separated into land and ocean fluxes. What we need is a standardised methodology to estimate the national fluxes based on these gridded data; such a methodology relies on a country mask, i.e., a grid that for each cell specifies which countries it belongs to.

The first issue to answer is the definition of a country for flux estimation applications. The main question here is how the coastal zones should be counted, i.e., are the borders along the coasts or should e.g. the Exclusive Economic Zones (EEZ) be included. This issue is more political than technical, and is not discussed further here.

We would recommend a strategy to create a dense country mask using the same ellipsoidal 0.1°x0.1° grid as the Global Emissions EDGAR v4.2 dataset from JRC (cf. http://edgar.jrc.ec.europa.eu/). Some regional models have the possibility to use map projection grids. For these models an interesting option, in Europe, would be to use the proposed European reference grid (based on ETRS89 Lambert Azimuthal Equal Area map projection, see http://inspire.ec.europa.eu/theme/gg); but this would require that meteorological data is available on, or transformed to, this grid.

Since the current inverse models are using different grids concerning geometric resolution, alignment and handling of polar regions, etc., spatial interpolation is required. Suitable interpolation methods for this purpose are conservative mapping methods on the sphere, see e.g. Jones (1999). The alternative of using several country masks for different grids (corresponding to the ones used for the inverse models) would inevitably lead to inconsistent country boundary definitions.

To create a country mask there are basically two things required. Firstly we need a vector dataset defining the country boundaries with sufficient resolution and quality, and secondly we need an appropriate methodology to derive the country mask based on these data. In Europe there are good datasets such as the *EuroBoundaryMap* (http://www.eurogeographics.org/products-and-services/euroboundarymap). This dataset has a spatial resolution corresponding to scale 1:100,000 (which is sufficient for creating a country mask on 0.1°x0.1°) and is regularly updated by the national mapping agencies. To find official sources for country boundaries on a global scale is not straight forward since there are disputes on several boundaries. Our understanding is that this prevents the official organisations to release global vector country maps, e.g. the World bank states on their homepage that "The maps displayed on the World Bank web site are for reference only. The boundaries, colours, denominations and any other information shown on these maps do not imply, on the part of the World Bank Group, any judgment on the legal status of any territory, or any endorsement or acceptance of such boundaries." (http://www.worldbank.org/en/about/legal/maps). This lack of official sources for global vector country boundaries gives that country masks should be based on other sources such as Digital Chart of the World (DCW), Global Administrative Areas (GADM, http://www.gadm.org/) or ESRI world topographic map.

To compute a correct country mask we need to overlay the vector country borders on the ellipsoidal grid (on e.g. 0.1°x0.1° degree resolution). From a computational point of view this overlay operation is a really demanding task, and therefore we could make a map projection simplification. Recommended projection is here Lambert cylindrical equal-area projection, since it conserves the meridians and parallel circles as orthogonal straight lines (besides having the equal area property). The simplification of using this projection is that a straight line between two break points in a line in Lambert cylindrical projection (below denoted a LCEAP line) is not the geodesic line (nor the rhumb line). The deviations between the LCEAP and the geodesic lines are small at equator and increase towards the poles and also increases for longer line segments. For e.g., our test of the ESRI world topography map has revealed a geometrical resolution corresponding to around 0.03°-0.05° between the break points on country boundaries, and for these short distances the LCEAP line approximation has less influence on the result than the uncertainty of the vector data. But for EEZ-border maps the distance between the break points could be so large that the LCEAP line approximation is not valid.

The output of several inverse models is GHG flux per areal unit for each cell in the grid. To compute the total flux for the cell we then need to multiply with the cell area. The question is then which cell area should be used here (and included in the country mask). One could argue that the cell area on an ellipsoidal model should be used, since it reflects the true area on ground, but the problem is that the inverse models could use a spherical grid area for normalisation in their model, which would then cause inconsistencies. On the other hand, a spherical approximation introduces on error in cell size of the order of up to one percent (depending on latitude and the size of the spherical/ellipsoidal earth model). One could argue that the geographic data used as input to the inverse models (as well as the country masks) should use authalic latitude, i.e. latitude on a sphere with the same surface area as an ellipsoid (cf. Snyder, 1987, p. 16). This is good in the way that the relative sizes of geographic features (land/sea relationship, vegetation, etc.) will be correct, but it will introduce horizontal shifts in the latitudes that will affect the inverse modelling result. As a result of this, one recommendation is that the country mask should only contain the partial values (corresponding to the overlap of a country) for each cell (summing up to one for each cell) and that the cell area should be stored separately. Whether the spherical or ellipsoidal cell areas should be used then depends on the construction of the inverse model.

2.3 Test implementations

ICOS CP plans to have services to estimate national GHG fluxes in the future. So far we have made some preliminary tests. The tests are based on collected GHG flux estimates from top-down inversions and bottom-up process-based flux models from the research community. To perform national/regional GHG flux estimations the following steps are performed:

- The modeled flux data is interpolated to a 0.1°x0.1° grid. The interpolation is done by the Python library PySCRIP (https://github.com/dchandan/PySCRIP), which is a Python wrapper to the Spherical Coordinate Remapping and Interpolation Package (SCRIP; http://oceans11.lanl.gov/trac/SCRIP) implementing the interpolation methods developed in Jones (1999).
- A country mask was created on 0.1°x0.1° resolution for the EEZ borders. This was done in ArcMap using ESRI world topography map and EEZ-borders from Marine Regions (http://www.marineregions.org/) using Lambert cylindrical equal-area projection. Parts of the creation of the county mask is done in own Python-scripts.
- Computation of national flux computations was performed in a Python-script.

All the Python-scripts are developed in a Jupyter notebook (http://jupyter.org/), which enables others (invited) to scrutinize the methodology used and possibly also make their own additions.

3 Concluding remarks

We foresee a future where the national GHG flux estimations and reporting are partly based on top-down modelling using inverse modelling. The GIScience community should contribute to this future reporting by assisting with data and methodologies for creating country masks. It is important that this is done in cooperation with official institutions such as JRC (European Commission Joint Research Centre) and UN-GGIM (United Nations - Global Geospatial Information Management) as well as with research institutions/infrastructures such as ICOS.

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